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COSTS AND BENEFITS OF THE INTEGRATED MAINTENANCE INFORMATION SYSTEM (IMIS)

Daniel Teitelbaum
Jesse Orlansky

May 1996

Prepared for
Office of the Under Secretary of Defense
(Personnel and Readiness)

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PREFACE

This paper was prepared for the Office of the Under Secretary of Defense (Personnel and Readiness) under a task entitled "Cost and Effectiveness of Multi-Media Training Technologies."

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This study was conducted for the Office of the Under Secretary of Defense for Personnel and Readiness under a task on "Cost and Effectiveness of Multimedia Training Technologies." Technical cognizance for this task was assigned to Gary Boycan, Readiness and Training Directorate.

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SUMMARY

In this paper we evaluate the effectiveness and cost savings of a computer-based, aircraft maintenance support system against the use of conventional, paper-based technical orders (TOs). The Integrated Maintenance Information System (IMIS) replaces paper-based TOs needed for maintenance with a portable device that guides technicians to efficiently diagnose faults on the flight line. It eliminates paperwork; improves the currency of technical data; and speeds up preparation of reports, work orders, and orders for spare parts.

The Air Force conducted a field test of IMIS on three sub-systems on the F-16 aircraft: fire control radar, heads-up display, and inertial guidance. Twelve avionics specialists and 12 APG technicians (non-specialists) were required to diagnose 12 faults in these systems; half of the fault isolation problems were handled using standard, paper-based TOs and half using IMIS. The measures used to score the test were percent of problems completed successfully, mean number of parts used, mean performance time to complete a problem, mean time to complete each part order, mean time to close out each problem, and mean number of major errors per problem. The results showed that using IMIS increased the percent of maintenance problems solved successfully, reduced the time needed to complete maintenance actions and order spare parts, and reduced the number of errors per problem, both for specialists and non-specialists. Specialists always performed better than technicians, whether both used IMIS or technical orders. On the other hand, technicians using IMIS always performed better than specialists using paper-based technical orders.

The results of these tests were used to estimate the cost savings obtained by using IMIS, after accounting for the costs of developing and using this system. We estimate the net savings from using IMIS for maintenance of the F-16 to be about $21.6 million per year (FY 1995 dollars) or about 0.5 percent of the annual budget for operations and maintenance of this aircraft. These findings suggest that use of IMIS technology should be extended to other complex systems of all Services, as has already happened for the F-22 aircraft and the Joint Surveillance and Targeting Attack Radar System (JSTARS). Potential savings that should be explored are reduced training as a result of wider use of IMIS, and

the possibility that technicians could be qualified to maintain a wider variety of aircraft than is now the case. Another benefit would be the value of more aircraft available for combat sorties because of reduced maintenance time and more accurate fault diagnosis. Finally, we note that it must be possible to accumulate small time savings into usable units of productive time before they can yield practical benefits.

I. PURPOSE

The purpose of this paper is to estimate the costs and benefits of using the Integrated Maintenance Information System (IMIS) to maintain F-16 aircraft. Recent field tests of IMIS provide performance data needed for an objective assessment of the worth of this method of maintenance (Thomas, 1995). Improved maintenance systems provide a means of decreasing the time and resources needed to perform aircraft maintenance, and of increasing the availability of aircraft for combat missions.

II. INTRODUCTION

To diagnose equipment malfunctions that can occur in a modern aircraft requires an enormous amount of technical information. Such an aircraft could not actually lift the many manuals needed to maintain it. Knowledge contained in these manuals is difficult, as well as inconvenient, to find and to use; it is also difficult and expensive to keep the information correct and up to date. Recognition of this problem has led to many attempts, based mostly on electronic data processing systems, to provide relevant information more quickly and conveniently to maintenance technicians while they are close to the aircraft.

The IMIS system of the 1990's is a logical development of efforts to improve maintenance that can be traced to the 1960's. Starting in 1965, Air Force Project PIMO (Presentation of Information for Maintenance and Operation) developed paper-based, task-specific Job Guides that improved both technical documentation and procedural guidance for maintenance (Serendipity, 1969). The Computer-Based Maintenance Aids System (CMAS) evolved from research on Job Performance Aids (JPA). Starting in 1977, CMAS developed basic concepts for presenting and accessing technical information on a computer; these concepts provided the foundation for the Interactive Electronic Technical Manuals (IETMs) that are part of IMIS. Inaba (1988) developed cards, called Job Performance Aids, that modified technical orders to provide logical guidance for diagnosing maintenance problems. A field evaluation of JPAs showed that they reduced maintenance errors by 92 to 100 percent.

JPAs have consistently improved technician performance beyond that achievable with conventional technical manuals (Booher, 1978; Foley, 1972; Smillie, 1985). JPAs, however, share with technical manuals the limitations inherent in paper-based materials: revisions and updates are expensive and frequently lag maintenance operations in the field because of delays in printing and distribution. Although a JPA provides the branching logic, the maintainer must still decide which branch to follow. It is difficult to design JPAs at a level of detail suitable for both novice and experienced personnel. Further, good JPAs are costly to develop, often more so than manuals, because of the extensive front-end analysis required. These cost increments are usually in addition to the costs of conventional technical manuals. The highly proceduralized task-specific approach characteristic of

JPAs, nonetheless, remains a compelling alternative to sole reliance on manuals for technical guidance.

The basic concepts for presenting technical information for maintenance were implemented in the Air Force in the form of Job Guides (which closely follow the JPA format), in the Navy in the form of Work Packages (in a format very similar to the JPA format) and in some Army manuals. The only portion of the JPA approach advocated by the Air Force that has not been fully implemented is the rigid task analysis process needed for developing JPAs; contractors have been permitted to substitute their own job analysis procedures.

From 1980 to 1987, the Army Research Institute and the Navy Personnel Research and Development Center joined efforts to develop a portable, computer-based information system that a technician could carry to support maintenance in a field environment. The program, and device, was called PEAM, for Portable Electronic Aid for Maintenance. The device was portable, permitted hands-free operation (using voice interactive input and output), and provided text and graphic presentations. A special effort was made to develop an authoring system that provided job guidance information in a meaningful and convenient order.

Tests of a prototype system showed that, compared to the use of paper-based information, PEAM decreased troubleshooting errors on the Navy Sea Sparrow Missile System by 84 percent and errors in non-diagnostic repair tasks by 60 percent (Smillie, Nugent, Sander, and Johnson, 1988; Wisher and Kincaid, 1989; Lane and Orlansky, 1989). However, this system was ahead of its time: the concept yielded a dramatic improvement in performance, but the technology then available was limited and unreliable (e.g., poor battery power and graphics, slow response time, high cost) in ways that no longer apply. The PEAM program was never implemented; about $10 million was spent on its development.

As this paper shows, the problem of maintaining complex equipment can be reduced by improved technology such as computer-based guidance. A related aspect to improved maintenance is the selection and training of personnel best able to perform maintenance and the availability, as well as cost, of manpower needed to maintain the many complex systems of our modern armed forces. There is a long-standing problem in that personnel selection and training, as well as system design and development, for particular systems tend to be treated independently even though, in practice, they have strong impacts on each other. Finally, it is reasonable to believe that reduced maintenance time can make more aircraft available for combat sorties.

III. F-16 MAINTENANCE AND THE INTEGRATED MAINTENANCE INFORMATION SYSTEM (IMIS)

In 1992, the Air Force adopted the concept of two-level maintenance (2LM) for new weapon systems, with the F-16 as an early application. The two levels are Organization (O-level) and Depot (D-level) Maintenance. Line Replaceable Units (LRUs) are diagnosed at the O-level; if a problem is found, the defective unit is removed and replaced, and sent to the depot for repair. At the depot, specialists sometimes find no problem (called Retest OK, RTOK) or are unable to duplicate the trouble (Cannot Duplicate, CND). Operational LRUs (those that have been repaired and those for which no problem was found) are returned to the organization for use on the flight line.

Through a single integrated system, IMIS provides avionics technicians access to all the technical information required to perform their jobs, thereby improving the efficiency of F-16 maintenance throughout the Air Force. The technician carries a hand-held computerized information system called the Portable Maintenance Aid (PMA); the PMA has a removable data storage cartridge (hard disk) with sufficient capacity to maintain all information required for an assigned maintenance task. Before the technician goes to the aircraft, the cartridge is loaded at a workstation in the squadron with the latest version of the technical data and any other required information. Given a particular, observed fault, the IMIS uses effectivity codes to select the data presented to the technician so that the procedures to be followed are relevant, correct, and appropriate for the specific model and block aircraft. The PMA provides step-by-step instructions for troubleshooting, remove, replace, and repair tasks. The PMA also keeps track of maintenance actions taken. This information is transmitted by radio or downloaded to the workstation when the technician returns to the shop. When the job is completed, the maintenance actions are added to the historical database. The PMA cartridge used in the field test at Luke AFB had sufficient storage capacity to maintain complete technical data for the three F-16 subsystems used in the test.

IMIS comprises three interdependent core capabilities: Interactive Electronic Technical Manuals (IETMs), Connectivity with Maintenance Data Systems, and Dynamic Diagnostics.

A. INTERACTIVE ELECTRONIC TECHNICAL MANUALS

IMIS replaces paper-based Technical Orders (TOs) with IETMs. This capability decreases repair times by giving maintenance personnel rapid access to the relevant sections of TOs and by improving the presentation of technical data to the technician. It also eliminates the requirement to manually post changes and updates to the paper TOs.

The reduction in errors results, in part, from the automatic evaluation of effectivity codes by the PMA. This capability ensures that the technician is using the relevant and correct technical data for the aircraft to be repaired. Serious errors can result if the technician uses technical data intended for another block of aircraft.

B. CONNECTIVITY WITH MAINTENANCE DATA SYSTEMS

IMIS provides flight-line maintenance personnel with direct, electronic access to the Core Automated Maintenance System (CAMS) and the Reliability Maintenance Information System (REMIS). IMIS provides base-level maintenance data to CAMS, which passes the information to REMIS. This capability eliminates paperwork, improves the accuracy of the data, and speeds up the current process for recording and reporting maintenance actions. It also provides managers with real-time access to maintenance reports, aircraft status, and work order status. IMIS also provides access to the Standard Base Supply System (SBSS) through CAMS. The ability to order parts via the radio link is a major source of time savings. Since the PMA automatically identifies the correct part number and orders it by radio, the technician no longer has to return to the shop, determine the part number, and go to the supply area to order the part.

C. DYNAMIC DIAGNOSTICS

IMIS has an integrated dynamic diagnostic capability, based on symptom/fault logic and probabilistic methods as well as historical, aircraft-specific maintenance information. For an aircraft with a maintenance bus, the PMA plugs into the bus to operate built-in tests (BITs), download system performance and status data, and dynamically determine the next diagnostic step, based on the BIT data. The dynamic diagnostics capability reduces maintenance troubleshooting time and the incidence of "Retest OKs" (RTOKs) and "Can Not Duplicates" (CNDs). Reducing RTOKs decreases requirements for mobility readiness spares and pipeline spares.

Our analysis uses data from two sources: a field test of IMIS performed in 1995 (Thomas, 1995) and a cost-benefit analysis of IMIS performed in 1992 (Tomasetti et al., 1993, 1994). We used the most recent data, from the Thomas report, to update and simplify Tomasetti's cost-benefit analyses.

Earlier field trials of IMIS were conducted at Luke AFB during November–December 1993 and June 1994 (Ward, Kruzick, and Weimer, 1995). They showed that, using the current methods, the average time needed to debrief pilots about discrepancies after a flight was greater than 13 minutes; using IMIS, the debrief time was about 6 minutes. They also recorded favorable and unfavorable observations about the use of various IMIS functional capabilities, e.g., diagnostics, electronic TOs, and flight line management support. Although these findings are useful for showing user acceptance and suggesting ways of improving the design and use of IMIS, they provide no data useful for a cost-benefit evaluation.

Thomas (1995) describes his test as follows:

> In the test, an experiment was conducted to evaluate the impact of IMIS on the performance of maintenance technicians. In the experiment, 12 avionics specialists and 12 non-specialists (airplane general [APG] technicians) performed 12 fault isolation problems on three F-16 subsystems: the Fire Control Radar (FCR), Heads-Up Display (HUD), and Inertial Navigation System (INS). Half the problems were performed using the current paper-based technical orders (TOs) and part-ordering and documentation procedures. The APG technicians were included in the study to determine if the use of IMIS would enable non-specialist technicians, with little or no training on a specific aircraft subsystem, to isolate and repair faults in that system at least as effectively as specialists, with specific experience and training on the system, using paper TOs.

The test to determine the impact of IMIS on F-16 operations was conducted with the 310th Fighter Squadron at Luke Air Force Base, Arizona, during the summer of 1994.

Table 1 reports the results of the field test. Thomas (1995) compared the performance of specialists and non-specialists, each group using both standard TOs and IMIS. Six measures of performance were used; percent of improvement due to the use of IMIS rather than the TOs is reported for each measure.

Table 2 summarizes improvements in performance due to the use of IMIS rather than TOs. Depending on the measure used, improvements due to IMIS range from 17 to 94 percent. As expected, technicians, who are less qualified than specialists, do not perform as well as specialists. On the other hand, IMIS permits them to show greater improvement. There can be no question, then, that IMIS supports greater effectiveness in performing maintenance than does the use of conventional TOs.

Table 1. Performance of 12 Avionics Specialists and 12 Non-Specialists[1] on 12 Fault Isolation Problems on Three F-16 Subsystems[2]

Measure	Personnel	Method of maintenance: TO	Method of maintenance: IMIS	Improvement	
				problems completed	
1. Percent of problems completed successfully	Avionics specialist	81.9%	100.0%		18.1%*
	APG technician	69.4%	98.6%		29.2
				parts saved	
2. Mean number of parts used by each technician for six problems under each condition	Avionics specialist	8.67	6.42	2.25	26
	APG technician	8.30	5.30	3.00	36
				time saved	
3. Mean performance time per problem (minutes)	Avionics specialist	149.29	123.64	25.65 min	17%*
	APG technician	175.82	124.04	51.78	29
				time saved	
4. Mean time to complete each part order (minutes)	Avionics specialist	19.42	1.16	18.26 min	94%
	APG technician	25.28	1.47	23.81	94
				time saved	
5. Mean time to close out each problem	Avionics specialist	14.67	8.17	6.50 min	44%
	APG technician	17.31	8.82	8.49	49
				fewer errors	
6. Mean number of major errors per problem	Avionics specialist	0.69	0.29	0.40	58% ns
	APG technician	1.06	0.18	0.88	83

Note: All improvements in this table are statistically significant at $p < .001$ except as noted:

* $p < .01$

ns not statistically significant

1 APG: Airplane general technician

2 Fire control radar, Heads-up display, Inertial navigation system

Data from Thomas (1995)

Table 2. Percent Improvement Due to Use of IMIS

Measure	Percent improvement with IMIS: Specialists	Percent improvement with IMIS: Technicians
Percent of problems solved	18%	29%
Number of parts used	26	36
Performance time	17	29
Time to complete part orders	94	94
Time to close out problems	44	49
Number of major errors per problem	58	83

In Table 3, we compare the performance of technicians who used IMIS with that of specialists who used conventional TOs—the current standard procedure. In every case, technicians using IMIS outperformed specialists using TOs. This result suggests that technology can substitute for costly, intensive, and prolonged advanced training; it also suggests the possibility (and probably the likelihood) of better, faster, and lower cost maintenance. These advantages indicate the need for trade-off evaluations between job aids and training to determine the more cost-effective mixes of the two. Thus, the remaining question for this paper concerns the costs and benefits of using IMIS, rather than TOs, for maintenance of F-16 aircraft, based on the test data reported by Thomas.

Table 3. Performance of Avionics Specialists Using Technical Orders and Non-Specialists Using IMIS

Measure	Performance		Advantage[3,4] of technicians	
	Specialist[1]	Technician[2]		
			problems completed	
1. Percent of problems completed successfully	81.9%	98.6%	16.7%	20.4%
			parts saved	
2. Mean number of parts used by each technician for six problems under each condition	8.67	5.30	3.37	38.9%
			time saved	
3. Mean performance time per problem (minutes)	149.29	124.04	25.25 min.	16.9%
			time saved	
4. Mean time to complete each part order (minutes)	19.42	1.47	17.95 min.	92.4%
			time saved	
5. Mean time to close out each problem	14.67	8.82	5.85 min.	39.9%
			fewer errors	
6. Mean number of major errors per problem	0.69	0.18	0.51	73.9%

1 Specialists with TO

2 Technicians with IMIS

3 $\text{Performance}_{\text{Specialist}} - \text{Performance}_{\text{Technician}}$

4 $(\text{Performance}_{\text{Specialist}} - \text{Performance}_{\text{Technician}})/\text{Performance}_{\text{Specialist}}$

IV. BENEFITS OF IMIS

Tomasetti, Calogero, Jones, et al. (1993) of Robbins-Gioia, Inc. report a thorough cost-benefit analysis of applying IMIS technology to the maintenance of F-16 aircraft. Table 4 is a summary of their results. Our analysis updates these results by using the data collected (Thomas, 1995) in the field test.

Table 4. IMIS Costs and Benefits (FY 93 Constant-Value Dollars)

	Core IMIS	Core IMIS with Remote Part Ordering
Nonrecurring Cost	$170.3 M	$174.4 M
Recurring Cost	59.2	60.2
Total IMIS Cost	229.5	234.6
IMIS O&S Benefits	903.8	938.2
Net IMIS LCC Savings	$674.3 M	$703.6 M

Data from Tomasetti, Calogero, Jones, et al. (1993), p. ix.

The field test measured only improvements among maintenance personnel. IMIS also saves pilot's debriefing time—some estimate by as much as 10 minutes per flight—and increases the availability of aircraft after a flight. This analysis, however, will be based solely upon the improvements documented in the field test, i.e., savings to pilots and other non-maintenance personnel are omitted.

The field test did not measure reductions in training time for maintenance personnel. There are plans to incorporate IMIS as a training tool, but any savings from increased training efficiency are not considered.

The wartime benefits of IMIS are also omitted. Improvements in maintenance efficiency should translate into reductions in downtime for fighter aircraft. This reduction in downtime could perhaps result in increased sortie capability. In practice, however, it is difficult to estimate the impact of downtime. If an aircraft which is scheduled for a sortie is unavailable due to maintenance problems, another aircraft is used as a substitute. Consequently, missed sorties rarely show up in the operations logs. To calculate the number of sorties missed, one would need to compare the plane flown to the plane scheduled for each sortie. No attempt was made to collect such data.

A. SAVINGS IN ORGANIZATIONAL-LEVEL (O-LEVEL) MAINTENANCE

At the O-level, IMIS will allow maintenance technicians to troubleshoot and repair problems more efficiently. "IMIS Benefits" are reductions in the F-16 Operations and Support (O&S) costs resulting from implementation of IMIS. The cost, benefit, and life cycle costs savings estimates (assuming an 8-year IMIS economic life) for Core IMIS and Core IMIS with a remote part ordering capability are given below. To calculate benefits due to IMIS, we assumed that specialists and technicians would each perform half of the maintenance tasks (that is, we used an average of their performance measures in the field trial, shown in Tables 1 and 2). Obviously, actual benefits could vary around this average, depending on the mix of personnel assigned to maintenance. The data come from Tomasetti et al., 1993.

Maintenance Manhours/Flying Hour (MMHr/ FlyHr) Derived by Robbins-Gioia from F-16 historical flying hour and maintenance manhour data in the MODAS[1] database.	$ 5.65
Total F-16 Flying Hours/Year (FlyHr/Yr)	452,790
Manhours/Year (ManHr/Year)	1,774
Annual Maintainer Salary (Accelerated E4)	$ 34,812
Number of Men Needed for Maintenance per year (#MM) MMHr/FlyHr * FlyHr/Yr ÷ ManHr/Year 5.65 * 452,790 ÷ 1,774	1,442
Percentage of Unproductive Time Spent by Maintenance Men Under the Present System	4%
Maintenance Man Costs/Year (MMCost/Yr) #MM * Salary 1,442 * $34,812/yr	$ 50,198,904
Annual Savings MMCost/Yr * Time Saved[2] * Unproductive time $50,198,904 * 0.232999 * (1–0.04)/yr	$11,228,443

1 MODAS: Maintenance and Operational Data Access System.

2 The value for Time Saved (0.232999) comes from Table 1, Mean performance time per problem (minutes). The time saved using IMIS was 17 percent by Avionics specialists and 29 percent by APG technicians; the average of these two values (23 percent) is used here. Calculations used more significant figures than are shown in the tables.

B. SAVINGS IN DEPOT-LEVEL (D-LEVEL) MAINTENANCE

IMIS results in fewer parts used by maintenance crews at the flight line. Fewer parts used means fewer parts sent to the depot, which saves maintenance time at the depot.

Total F-16 Flying Hours/Year (FlyHr/Yr)	$ 452,790
Depot Cost/Flying Hour (DCost/FlyHr) (Robbins-Gioia, FY93)	331
Percentage of parts sent to the depot which are RTOK[1] (%RTOK) (Robbins-Gioia, FY93)	0.2666
Reduction in RTOK's (RedRTOK)[2]	0.311321
Annual Savings FlyHr/Yr * DCost/FlyHr * %RTOK * RedRTOK 452,790 * $331 * 0.2666 * 0.311321	$12,439,227

1 RTOK: Retest OK.

2 This value (0.311321) comes from Table 2, Number of parts used. Using IMIS, specialists improved 26 percent and technicians improved 36 percent; the average of these two values is 31 percent. Calculations used more significant figures than are shown in Table 2.

C. SAVINGS IN TRANSPORTATION OF PARTS

Fewer RTOK's means fewer parts sent to the depot. Fewer parts sent to the depot results in a savings in the cost to transport parts to and from the depot.

RTOK Transfer Cost (Robbins-Gioia, FY92)	$2,866,953
Savings (RedRTOK * RTOK transfer cost) 0.311321 * $2,866,953	$892,543

D. SAVINGS IN MOBILITY READINESS SPARES PACKAGE (MRSP) TRANSPORTATION

The MRSP is an air-transportable package of spare parts necessary to sustain planned wartime or contingency operations. The MRSP is supplied for a specified period (usually 30 days); composition of the MRSP is based on historical trends and projections of requirements. With IMIS, the size of the MRSP could be reduced, making it lighter and less expensive to transport.

MRSTP Transportation Cost (Robbins-Gioia, FY92)	$2,140,086
Savings (RedRTOK * MRSTP Transportation cost) 0.311321 * $2,140,086	$666,254

E. SAVINGS IN PIPELINE SPARES INVENTORY (PSI)

Pipeline spares are the Line Replaceable Units (LRUs) and Shop Replaceable Units (SRUs) needed to ensure that sufficient stock levels are available for the order and shipment pipeline from the depot to base (demand for new/repaired items) and base to depot (demand items to be repaired). The composition of the pipeline is based on the specified repair level (base or depot) for the systems LRUs and SRUs and on the projected failure rates.

Value of the PSI (VPSI) (Robbins-Gioia, FY92)	$252,335,936
One-time PSI Savings (RedRTOK * VPSI) 0.311321 * $252,335,936	$78,557,414

Since the composition of the PSI is based on historical, pre-IMIS part failure rates, and we can expect these rates to drop, the PSI can be reduced by 31 percent. Parts that fail can now be replaced from this newly formed surplus; this surplus can, in effect, be considered a one-time gift of 31 percent of the PSI, but it is not a recurring benefit.

The annual benefit from the PSI savings depends on interest rates and the length of time necessary to exhaust the PSI surplus. The Robbins-Gioia analysis assumes an 8-year time horizon and 4.3 percent interest. If we assume that the PSI surplus is exhausted in 8 years, the annual benefit becomes:

Annual PSI Savings	$12,688,305

There are several ways to derive this number. The Robbins-Gioia analysis is unclear about the choice of formulation. Our formulation assumes that the value of spare parts appreciates; if the cost to buy a part increases over time and the pipeline spare surplus will be used to replace parts over time, this is in fact the case. On the other hand, one could argue that their value depreciates as the parts grow older.

It is important to note that the savings in the PSI is by far the largest single factor in the Robbins-Gioia analysis. Moreover, the estimate of this value increased by $150 million from 1992 to 1993, which demonstrates the liquid nature of cost estimates.

F. TOTAL ANNUAL BENEFITS FROM IMIS

The total annual benefit from IMIS is the sum of all of the annual benefits calculated so far.

Annual Benefits		
O-level maintenance		$11,228,443
D-level maintenance		12,439,227
Transportation of parts		892,543
MRSP transportation		666,254
Pipeline spares		12,688,305
	Total	$37,914,772

G. COSTS OF IMIS

Robbins-Gioia (1994, cost-benefit analysis) estimated the costs to develop and maintain IMIS:

Development	
Systems Engineering and Program Management	$1,916,051
PMA Equipment Development	1,624,525
MIW[1] Equipment Development	79,978
Dynamic Diagnostics	4,487,402
Independent Verification and Validation	987,228
System Integration, Test and Evaluation	1,100,000
Data Conversion	54,579,530
Deliverable Data	188,500
Training Course Development	136,382
Training Manual Development	46,059
MIW Equipment	13,297,138
Support Equipment	857,708
Technical Data and Manuals	159,324
Management Data	1,781,700
Instructor Training	126,294
Training Manuals	96,387
Site Surveys	3,714
Site Implementation Cost	32,889
Total (converted to FY 1993 dollars)	$81,481,809

1 Maintenance Information Workstation

Maintenance		
System Management		144,000
Utilities		23,324
Consumables		695,692
Hardware Maintenance		5,055,779
Software Maintenance		395,456
	Total	$6,314,251

Development costs are considered to be nonrecurring (sunk). These costs are summed, converted to 1993 dollars ($81,481,809), and then amortized over an 8-year life span ($11,748,983/year). The maintenance costs are considered to be recurring. The sum of these costs is $6,314,251. The total annual costs equal the amortized sunk costs plus the maintenance costs.

Total Annual Cost (FY93 dollars)		
Development (8-yr amortization)		$11,748,983
Maintenance		6,314,251
	Total	$18,063,234/yr

H. NET IMIS BENEFITS

The net benefit of IMIS is simply the gross annual benefits minus the gross annual costs:

Total Annual Benefits (FY93 dollars)		$37,915,449
Total Annual Costs		– 18,063,234
	Total	$19,852,215/yr

This value is expressed in 1993 dollars. Converted to 1995 dollars, the net benefit of IMIS is $21,596,212/year.

V. DISCUSSION

As with any cost-benefit analysis, this analysis is based on tacit, as well as explicit, assumptions. It is assumed, for instance, that there is a linear relationship between the value of small and large amounts of time, i.e., the value of any hour of an avionics technician's time is equal to his annual salary divided by the number of hours he works in a year. In reality, and especially for large organizations like the United States Air Force, this relationship is probably a nonlinear one. There exists an internal friction—a hysteresis effect—which causes money to be lost when salary is multiplied by time to get benefits. Such hysteresis has not been discussed explicitly, but it should be considered, especially in large organizations, to arrive at reasonable estimates of benefits accruing from technological innovations.

Many tasks are not infinitely divisible. If a person, for instance, was granted an extra 10 minutes a day, it would be foolish for him to allot that time to oil painting. An oil painting cannot be completed in daily, discrete, 10-minute intervals. It would take that long just to get the materials ready at the start and, again, to clean them at the end. Ten minutes a day is worth very little if that time must be spent in small units each day. Ten minutes a day is far more valuable if the time can be accumulated and spent as a unit at the end of each week.

In the case of avionics technicians, maintenance crews are currently minimally manned. And, if no sorties are being postponed due to maintenance backups, all IMIS would accomplish would be to increase idle time among technicians. Eventually, the maintenance crews' new-found free time could be turned into productive work, but initially, a large portion may simply be left unproductive. In organizations, where inertia is great, it can take months to discover and turn unproductive time into useful work. Military cost-benefit analyses must account for this.

Much critical, non-scheduled maintenance is performed during aircraft launch or surge operations where time is critical. In this case, the time saved means that aircraft will be released more quickly for sorties and more flights can be turned in a given time. Such time savings could have major benefits in surge situations, where time saved is critical.

The value (V_s) of time saved (T_s) must be less than or equal to the rate the employer is paying (V_p), where V_p for any unit of time (T) = S*T/year, where S is the employee's salary. We know, then, that $V_s/V_p \leq 1$.

The value of a unit of time saved depends on several factors: the length of time (T), the pay rate (V_p), the minimum length of time (T_m) required for work on a given project to be of non-zero value (if it takes 20 minutes to get the necessary tools and 15 minutes to clean up, 25 minutes is worthless), the ability of management to reallocate an employee's time (A), and the value of unproductive time (V_u), which is assumed to be zero. We have, then, $V_s = f(T, V_p, T_m, A, V_u, \varepsilon)$, where ε is an error term for any relevant factor not included in this model:

$$V_s = (T - T_m) * A * V_p + \varepsilon$$

where

V_s	=	value of time saved
T	=	unit of time
T_m	=	minimum length of time
A	=	ability to reallocate an employee's time
V_p	=	pay rate
ε	=	error term

The implication of this model is that researchers who are now collecting on-site IMIS data need to document not only the length of time saved, but also the increase, if any, in unproductive time. If technological innovations which save time also increase unproductive time in the short run, this result should be documented.

Several issues that warrant additional examination are discussed briefly here.

A. TRAINING IMPLICATIONS

The field trial shows that less well-trained people, i.e., technicians, can effectively maintain aircraft, if they can use IMIS. It makes sense to get an estimate of how much the Air Force spends each year providing institutional training to aircraft maintenance personnel. Adopting IMIS would allow that amount to be reduced by some percentage.

A discussion of the magnitude of this potential savings could strengthen the argument for using IMIS, not only for the F-16 but for other aircraft and complex systems as well.

That IMIS permits non-specialists to perform as well as or better than specialists has great significance for the selection and training of maintenance personnel: in general, to enlarge the pool of manpower able to perform maintenance and to reduce the amount and cost of training personnel needed to maintain the F-16. This finding also suggests that more flexible assignment of maintenance personnel to maintain a wider range of aircraft may be accomplished, if each has IMIS-type support systems. What works for the F-16 should also work for other aircraft and complex systems. These possibilities deserve more extensive evaluation than was possible in this paper.

It is of interest to point out that the PMA, used as a job-aiding device in IMIS, could also be used to train technicians in diagnostic procedures and problem-solving skills. In this role, IMIS would be modified to be a simulator. It could present fault-isolation problems at various levels of complexity and evaluate performance, both to guide instruction and to assist in evaluating student competence. An IMIS tutor could obviously be used in technical schools, field training detachments, and on-the-job training in squadrons (Hicks, Gugarty, Young, et al., 1995; Wilson, Walsh, Arnold and Daly, 1996).

B. OTHER COST SAVINGS

This paper has focused narrowly on the cost-effectiveness of IMIS for the F-16. It would be useful to extrapolate the F-16 data to estimate the impact of IMIS on the entire Air Force. In 1993, the cost of operating F-16s was about 12 percent of the cost of operating all aircraft. Thus, the benefits of using IMIS throughout the Air Force might be about eight times as great as using it for the F-16 alone. The costs of extending IMIS should also be considered. Some fixed costs (like equipment design) would not have to be borne again.

This report does not consider the savings resulting from elimination of the requirement to print, distribute, and update paper technical manuals. The savings from reduced printing and distributing costs are obvious. Less obvious are savings from elimination of the requirement to manually replace updated pages in technical orders. At present, each squadron may have from two to four people who do nothing but update technical orders. Eliminating this requirement alone would result in major savings over the lifetime of an aircraft system.

C. WARTIME IMPLICATIONS

The wartime implications of reduced downtime because of maintenance might be estimated using a sortie generation model like Dyna-METRIC. Analysis of this sort might show substantial benefits. The test clearly showed that use of IMIS reduced mean performance time to complete a maintenance problem by 26 minutes for specialists and by 52 minutes for technicians; using technical orders, specialists required 149 minutes per problem and technicians required 176 minutes (Table 1). This suggests that shorter delays due to maintenance could increase the number of sorties achievable in a combat scenario. That there were fewer major maintenance errors and a larger percent of problems completed successfully must also increase the number of combat sorties that can be conducted. If this argument holds, IMIS could improve the combat effectiveness of an aircraft squadron by producing more sorties at no increase in the number of aircraft required or by producing the same (i.e., required) number of sorties with fewer aircraft (i.e., at less cost). The Air Force uses the Dyna-METRIC model, produced by RAND, to examine such issues.

Reduction in the number of RTOKs among components received for processing at Depot-level maintenance means that fewer spare parts must be maintained in critical stockpiles; there would also be reduced transportation loads of equipment that travel for no good reason. Because spare parts represent a high value item in logistic support of combat forces, the implications of IMIS on this problem should be examined.

D. TEST LIMITATIONS

The IMIS field test provided strong evidence that this system has significant utility (Thomas 1995a). Nevertheless, the test had limitations which, if corrected or removed, could only enhance the utility of IMIS. These limitations are noted here:

1. Data in the Portable Maintenance Aids were converted from existing paper TOs. As a consequence, some illustrations and diagnostic tests were inadequate.
2. For most effective maintenance, the aircraft system must be designed with sufficient test points to allow fault isolation to a single component. In some cases, adequate test points were not available.
3. IMIS diagnostics may be more appropriate for some subsystems than for others (such as complex systems with lengthy, complex, troubleshooting procedures). This test was not designed to examine the most appropriate applications of IMIS to the test airplane; only three subsystems (fire control radar, heads-up display, and inertial guidance) were included.

VI. CONCLUSIONS

The current method of using paper-based TOs for maintenance of complex systems is cumbersome, outdated, and costly. In its place is IMIS, a portable, computer-based device that a technician can carry to an airplane on the flight line. IMIS provides the technical information needed to efficiently diagnose faults (based on symptoms and effectivity data), improves the currency of technical data, and uses local radio to prepare work orders and orders for spare parts.

The Air Force conducted a field test of IMIS on three sub-systems on the F-16 aircraft: fire control radar, heads-up display, and inertial guidance. Twelve avionics specialists and 12 APG technicians (non-specialists) were required to diagnose 12 faults in these systems; half of the fault isolation problems were handled using standard, paper-based TOs and half using IMIS. The measures used to score the test were percent of problems completed successfully, mean number of parts used, mean performance time to complete a problem, mean time to complete each part order, mean time to close out each problem, and mean number of major errors per problem. Compared to the use of paper-based TOs, IMIS improved the maintenance performance of specialists and of technicians on all measures of maintenance: that is, there were more problems completed, more parts saved, fewer errors, and faster performance times. The performance of technicians using IMIS was superior in all measures to that of specialists using paper-based TOs.

The use of IMIS technology probably has additional benefits that were not examined in this paper. These include the use of IMIS for the maintenance of other aircraft and complex systems of all Services; it will be applied to the F-22 aircraft and the Joint Surveillance Targeting Attack Radar System (JSTARS). The ability of technicians using IMIS to perform as well as specialists using TOs suggests potential savings in training and the number of personnel who have to be trained, as well as more efficient allocation of manpower to specialist and technician billets.

Two questions deserve additional attention:

- What are the criteria to identify systems that can benefit most from the use of IMIS?

- How do we ensure that the many small time savings obtained from using IMIS can be aggregated into productive blocks of time?

Finally, the suggestion that reduced maintenance time can be used to produce more sorties per aircraft in a combat environment or to support a required sortie load with fewer aircraft should be investigated.

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GLOSSARY

2LM	Two Level Maintenance
3LM	Three Level Maintenance
APG	Airplane General
BIT	Built-In Test
CAMS	Core Automated Maintenance System
CMAS	Computer-Based Maintenance Aids System
CND	Can Not Duplicate
Dyna-METRIC	Dynamic Multi-Echelon Technique for Recoverable Item Control (model)
FYDP	Future Years Defense Program
IETM	Interactive Electronic Technical Manual
IMIS	Integrated Maintenance Information System
JPA	Job Performance Aid
JSTARS	Joint Surveillance and Targeting Attack Radar Systems
LCC	Life Cycle Costs
LRU	Line Replaceable Unit
MODAS	Maintenance and Operational Data Access System
MIW	Maintenance Information Workstation
MRSP	Mobility Readiness Spares Package
O&S	Operations and Support
PEAM	Portable Electronic Aid for Maintenance
PIMO	Presentation of Information for Maintenance and Operation
PMA	Portable Maintenance Aid
PSI	Pipeline Spares Inventory
REMIS	Reliability Maintenance Information System
RF	Radio Frequency
RTOK	Retest OK
SAF	Secretary of the Air Force
SBSS	Standard Base Supply System
SRU	Shop Replaceable Unit
TO	Technical Order
VPSI	Value of Pipeline Spares Inventory

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13. ABSTRACT ***(Maximum 180 words)***

The Integrated Maintenance Information System (IMIS) replaces paper-based technical orders as a means of providing technical information needed to maintain F-16 aircraft. Technical information can be accessed on a computer-based portable device that is carried to the aircraft to assist in the diagnosis of faults. A field test of IMIS on three F-16 aircraft subsystems showed that, compared to the use of paper technical orders, IMIS can save time needed to diagnose malfunctions, order spare parts, complete repairs, and increase the number of correct diagnoses. Improvements were found among technicians who had not received special training as well as among specialists who had. The performance of general aviation technicians using IMIS was, on every measure taken, superior to that of specialized technicians using paper technical orders. These improvements suggest that use of IMIS can save about $21.6 M per year of the cost to maintain F-16 aircraft, after accounting for costs of developing and using IMIS. It must be possible to accumulate small time savings before they can produce actual savings. It appears reasonable to extend IMIS technology to the maintenance of other complex systems. Potential benefits include reduced training, an enlarged manpower pool for maintainers, and increased availability of aircraft for combat sorties because of reduced maintenance time.

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